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Luminous Stars in Galaxies Beyond 3 Mpc

Bradley C. Whitmore¹

¹*Space Telescope Science Institute*

Abstract. I am mainly interested in the formation and destruction of young star clusters in nearby star forming galaxies such as the Antennae, M83, and M51. One of the first analysis steps is to throw out all those pesky stars that keep contaminating my young cluster samples. Recently, spurred on by our new WFC3 Early Release Science data of galaxies including M83, NGC 4214, M82, NGC 2841, and Cen A, we began taking a closer look at the stellar component. Questions we are addressing are: 1) what are the most luminous stars, 2) how can we use them to help study the destruction of star clusters and the population of the field, 3) what fraction of stars, at least the bright stars, are formed in the field, in associations, and in compact clusters. In this contribution we describe some of the beginning steps in this process. More specifically, we describe how we separate stars from clusters in our galaxies, and describe how candidate Luminous Blue Variables (LBVs) and “Single Star” HII (SSHII) regions have been identified.

1. Introduction

The ability of the Hubble Space Telescope to resolve star clusters in nearby galaxies has lead to rapid growth in this field in the past two decades. For example, the discovery of candidate young globular clusters in NGC 1275 by Holtzman et al. (1995) and the subsequent studies of the Antennae by Whitmore et al. (1995, 1999, 2007, 2010a) have shown that it is possible to study the formation of these systems in the local universe rather than having to try to figure out how they formed some 13 Gyr ago. However, most of the work on individual stars has remained focussed on the Milky Way and nearby Local Group galaxies. In this contribution we point out a few examples of what is possible working on individual stars in galaxies more distant than 3 Mpc.

One of the first analysis steps for studies of star clusters in galaxies is to identify and then “throw out” all the stars that would otherwise contaminate the cluster sample. Recently, spurred on by our new WFC3 Early Release Science (see Chandar et al. 2010) data of galaxies including M83, NGC 4214, M82, NGC 2841, and Cen A, we began taking a closer look at the stellar component. This was largely motivated by the improved quality of the $U - B$ vs. $V - I$ diagrams enabled by the increase in the discovery efficiency of WFC3 by a factor of ≈ 50 over ACS (due to larger field of view) and WFPC2 (due to higher quantum efficiency). An example is shown in Figure 1, which is taken from Chandar et al. (2010).

The quality of the agreement between the Bruzual-Charlot cluster models and the observations is excellent (e.g., upper left panels in Figure 1). This bodes well for the ability to age date clusters using the new generation of WFC3 observations. However, in the context of this meeting, the excellent agreement of the photometric observations

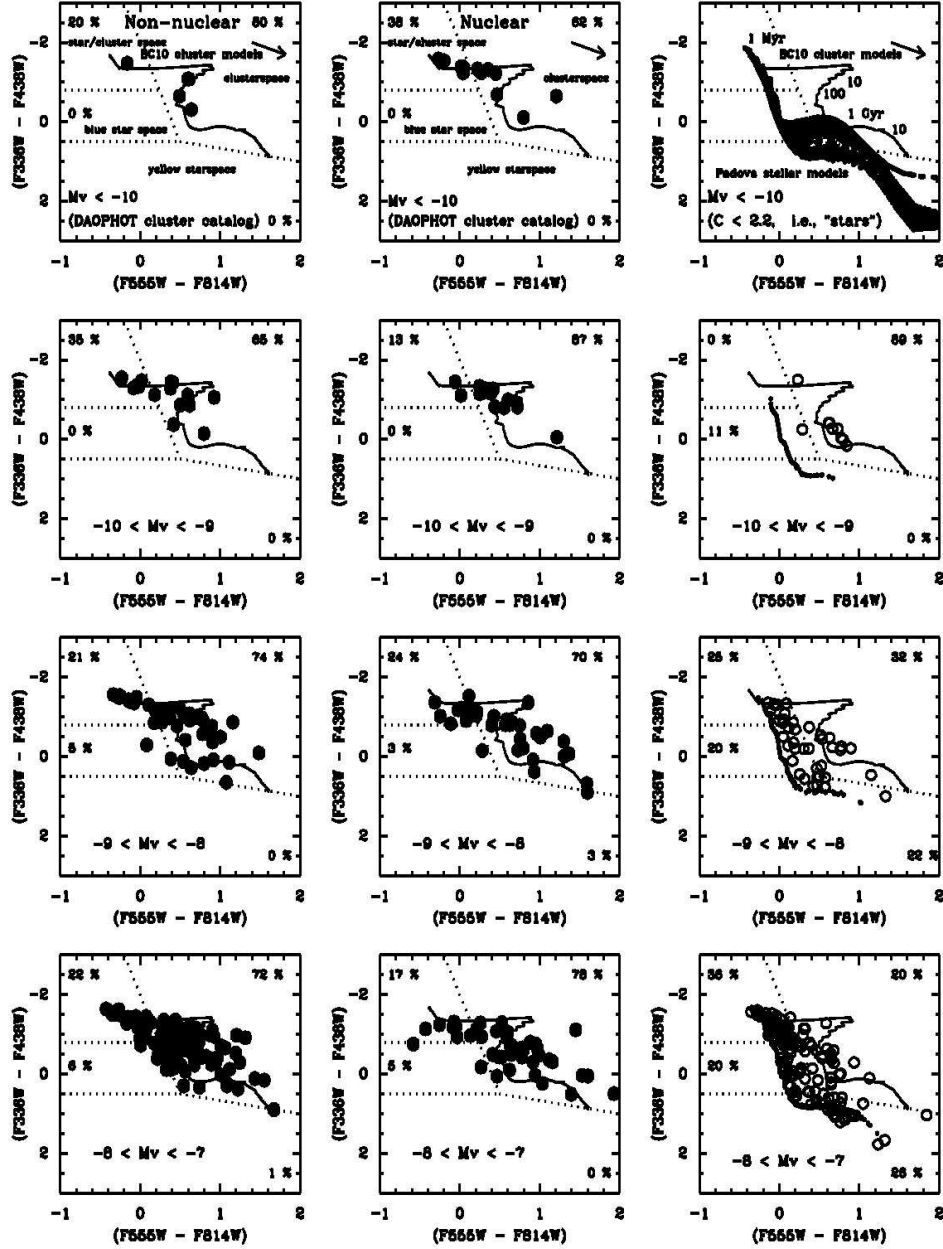


Figure 1. $(U-B)$ vs. $(V-I)$ two-color diagrams for cluster candidates that are outside the nuclear region in M83 (first column of panels), within the nuclear region (middle column of panels), and for stellar candidates throughout the galaxy (based on resolution; along the right column of panels). Each row shows objects in the indicated magnitude range, starting with bright sources at the top and moving to fainter objects at the bottom. The solid line shows predictions in the appropriate WFC3 filters from the cluster models of Bruzual & Charlot (2010 – private communication, but see also Bruzual & Charlot 2003). The line of small dots in the panels on the right show the predicted Padova isochrones for individual stars of the appropriate luminosity. See Chandar et al. (2010) for details.

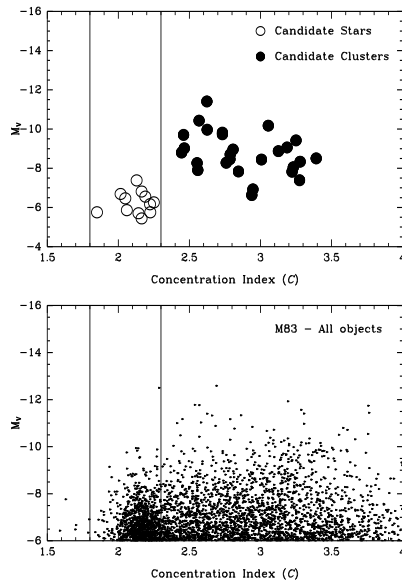


Figure 2. Values of the concentration index C , the difference between magnitudes measured within a 0.5 and a 3 pixel radius, are plotted versus the absolute magnitude in the V band (corrected for foreground extinction but not for extinction in M83). The upper panel shows that hand-selected stars (open circles) and star clusters (filled circles) separate nicely, and the lower panel shows the distribution for all objects detected in our field. The vertical lines show the approximate range in C found empirically for point sources. See Chandar et al. (2010) for details.

of candidate stars (e.g., the bottom right panel) with the Padova stellar models, suggests that the study of individual stars with WFC3 is likely to be equally enhanced.

2. Separating Stars and Clusters

The simplest way to separate stars and clusters in HST images is to use their size, since most clusters are slightly resolved out to distances of at least 20 Mpc (e.g., the Antennae; see Whitmore 2010). Figure 2 shows that this works very well for isolated, high signal-to-noise objects, but starts to break down for crowded fields and fainter objects (i.e., the bottom panel in Figure 2). Because of this, we began to investigate using color information to help make this distinction. For example, in Figure 1 the color-color plane is broken into 4 regions, two of which (“blue-star space” and “yellow star space”) can be used fairly straightforwardly to isolate stars. The upper left of the diagram is more problematic since both the Bruzual-Charlot cluster models and Padova stellar models occupy the same region (hence the name “star/cluster space”). The vast majority of the objects in “cluster space” are indeed clusters, but as we will see in Section 3, candidate Luminous Blue Variables (LBVs) may also be found here. See Chandar et al. (2010) for a full description of this approach for M83, and Whitmore et al. (2010) for a similar discussion for the Antennae.

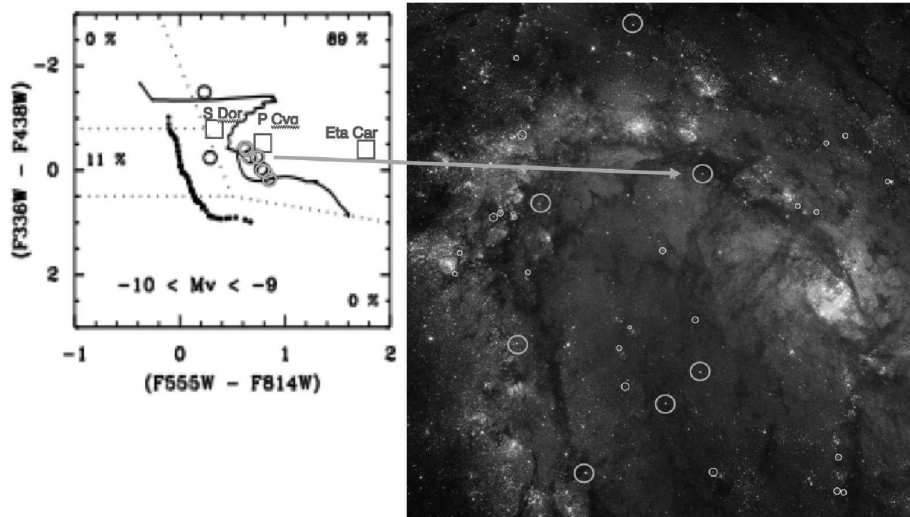


Figure 3. Blowup of the color-color diagram in the range $-10 < M_v < -9$ for candidate stars from Figure 1, with the locations of the objects with anomalous colors marked by large circles on the right image. The locations of “Single Star” HII regions, discussed in Section 4, are marked with small circles. The colors of three famous LBVs (S Dor, P Cyg, Eta Car) are shown using squares in the left figure. These have values of M_v that range from -8.9 to -10.5 magnitudes; very similar to the brightest candidate stars in M83.

3. Stars with Anomalous Colors – LBV Candidates?

The panels along the right panel in Figure 1 show candidate stars, based on the fact that their light profile match the point spread function of stars. In practice, we determine this using the “concentration index (C)”, which is the difference in magnitude determined from aperture photometry with a 3 and a 0.5 pixel radius. The full set of Padova stellar models are shown in the upper right figure (since there are no candidate stars with magnitudes $M_v < -10$). In the panels below, only the portion of the Padova model appropriate for the appropriate magnitude range listed in the panel are included. In the bottom two panels, most of the candidate stars are where we expect them, namely just to the right of the models. This slight redward offset is due to moderate levels of reddening. However, in the $-10 < M_v < -9$ panel, we find a tight knot of seven objects well off the Padova models, with $U-B \approx 0$ and $V-I \approx 0.8$. What are these objects? If they are stars, they have very anomalous colors.

We believe that these may be relatively rare, luminous blue variable stars (LBVs) in M83, since they have colors and luminosities similar to LBVs in the Galaxy and Magellanic Clouds, as shown in Figure 3. For example, three of the best known LBVs, Eta Carina, P Cygni, and S Doradus, have median colors of $U-B = 0.6$ and $V-I = 0.8$ and values of M_v between -8.9 and -10.5 mag.

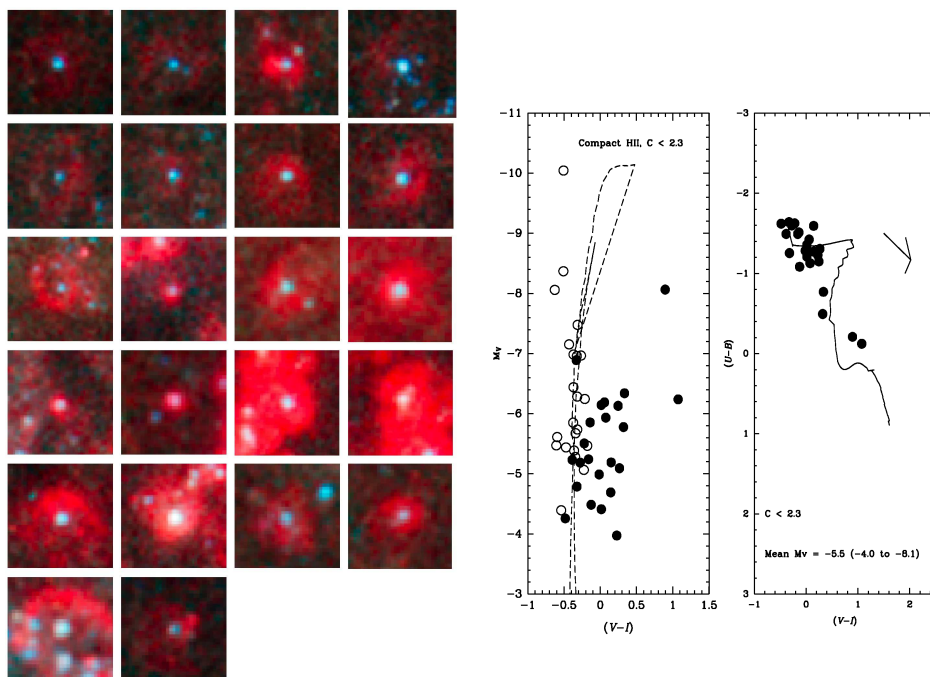


Figure 4. Left – Mosaic of the 22 “Single Star” HII (i.e., SSHII) region candidates. Middle – Color magnitude diagrams for the SSHII region sample. The filled circles show the observed values while the open circles show the corrected values based on the extinction derived from the color-color diagram (see text). Right – Color-color diagrams for the SSHII region sample. See Whitmore et al. (2010b) for details.

4. “Single Star” HII Regions

HII regions can be used to identify stars and cluster that are less than 10 Myr year old, since the O and B stars needed to ionize the hydrogen are gone by then. Whitmore et al. (2010b) uses this fact to study the ages of the star clusters in M83. They take this basic idea one step further and attempt to age date the clusters based on the size of the $H\alpha$ bubble, and the degree to which the young bright stars are resolved.

A sidelight to this study was the identification of a set of compact HII regions which appear to have a single star as the ionizing source. They identify a sample of 22 “Single Star” HII regions (SSHII) based on their concentration index, as defined above. Images of the sources are shown on the left side of Figure 4. The measured colors of these sources, shown on the right side of Figure 4, either coincide with the predicted colors for the bluest (young) stars in the upper left portion of the diagram, or are found downstream along the reddening vector.

It is unlikely that most of these stars are actually individual massive stars, hence the use of quotes around “Single Star.” Many, or even most of these objects likely reside within groups of stars which are either too close to the primary source, or too faint, to be detected. What we can say is that a single (or very close binary) star dominates the light profile, resulting in a concentration index that is indistinguishable from a single star.

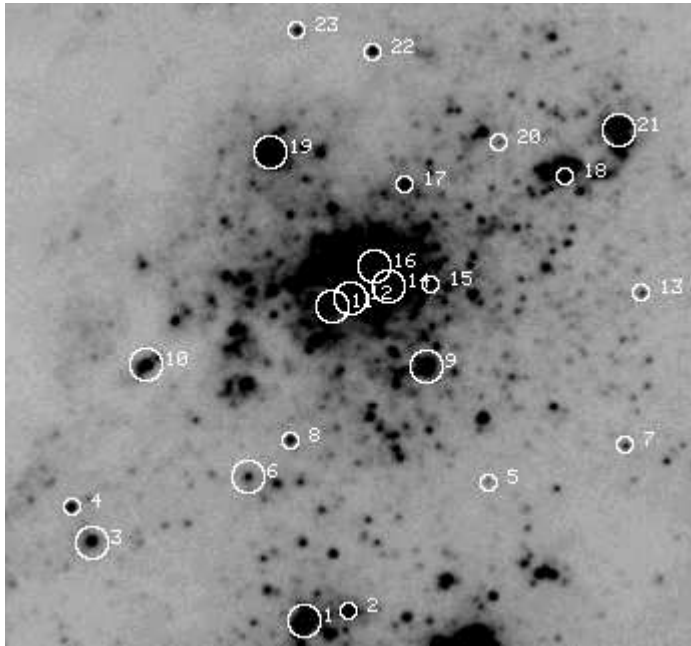


Figure 5. Region S in the Antennae; a region with a mass of $\approx 10^7 M_{\odot}$. Objects with small circles are candidate stars, demonstrating that individual luminous young stars can be studied in a galaxy as far away as ≈ 20 Mpc with HST relatively easily.

If we assume that all of these objects have similar ages, and that the distribution in the two-color diagram is primarily due to reddening, we can correct for the effects of reddening and extinction. We show the corrected photometry in a color magnitude diagram in the middle panel of Figure 4. Here, we have assumed an intrinsic color of $U - I = -2.2$, the color of the bluest object, and solved for the color excess of each HII region. We find that this procedure moves most of the objects to a very young isochrone (4 Myr is shown), as expected.

5. Summary

WFC3 data represent a quantum jump in our ability to study cluster populations in nearby galaxies. A byproduct of this is the ability to study individual stars in detail for stars beyond 3 Mpc. In this contributions we:

1. Demonstrate how both size and color information can be used to separate stars and clusters.
2. Find a population of stars in M83 that may be LBVs.
3. Identify a population of “Single Star” HII regions (SSHII) in M83. Many of these are in the field, showing that not all stars form in clusters.

One might ask the question how much beyond 3 Mpc is it possible to perform similar studies. Without trying to set a limit, we simply note that it is straightforward

to observe individual young stars in galaxies such as the Antennae galaxies (≈ 20 Mpc), as shown in Figure 5 (from Whitmore et al. 2010a).

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References

- Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000
Chandar, R., Whitmore, B. C., & Fall, S. M. 2010, ApJ, in press (arXiv:1002.3314)
Holtzman, J. A., Burrows, C. J., Casertano, S., Hester, J. J., Trauger, J. T., Watson, A. M., & Worthey, G. 1995, PASP, 107, 1065
Whitmore, B. C., Chandar, R. C., & Fall, S. M. 2007, AJ, 133, 1067
Whitmore, B. C., Chandar, R., and 23 other authors (the WFC3 ERS team) 2010b, in preparation
Whitmore, B. C., Chandar, R., Schweizer, F., Rothberg, B., Leitherer, C., Rieke, M., Rieke, G., Blair, W. P., Mengel, S., & Alonso-Herrero, A. 2010a, AJ, 140, 75
Whitmore, B. C., & Schweizer, F. 1995, AJ, 109, 960
Whitmore, B. C., Zhang, Q., Leitherer, C., Fall, S. M., Schweizer, F., & Miller, B. W. 1999, AJ, 118, 1551